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Circular No. 679
October 1943 • Washington, D. C.
UNITED STATES DEPARTMENT OF AGRICULTURE

Production and Fertilizer Use of Urea[1]

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INTRODUCTION

Nitrogen is vitally essential to the war effort for two reasons: For the production of munitions of different kinds and for the production of food.

The role of nitrogen in any food-production program is very important. Although nitrogen compounds are present in all cultivated soils, there is seldom enough to promote maximum crop production, and this makes it imperative to use nitrogen compounds as fertilizers. It is hardly necessary to state that a serious reduction in the supply of nitrogen fertilizers would imperil both our food- and feed-production programs and that an abundant supply of nitrogen and other commercial plant foods would lead to the production of greater and more nutritious crops.

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[1] This circular presents general information pertaining to the production and fertilizer use of urea. No special attempt has been made to offer specific recommendations as to time, rate, and methods of applying urea. Specific information concerning its use for fertilizer purposes may be obtained from State agricultural experiment stations, county agricultural agents, or the United States Department of Agriculture.

[2] The part of this circular that concludes with the section Cost of Nitrogen in Fertilizer Materials was contributed by Albert R. Merz; the remainder, which commences with the section Urea in Relation to Crop Production, by Bailey E. Brown.

Urea, now used extensively as a nitrogen fertilizer material, has been produced commercially in the United States only within the last decade. Recognition of its value has resulted from considerable experimental work on different crops and from the practical experience of farmers, horticulturists, and gardeners.

Although used as a constituent of liquid manure since the dawn of agriculture, urea was first produced artificially by Wöhler in 1828. It received little consideration as a commercial fertilizer material for nearly a century afterward, primarily because it cost too much to produce in competition with standard fertilizer materials. The work of chemical engineers, however, beginning abroad about 1920 and some 10 years later in the United States, has served to overcome this handicap.

Like ammonium sulfate, urea is obtained commercially solely as a manufactured product. Although the quantity available for use in fertilizers in the spring of 1943 was probably limited to about 25,000 tons, the production is understood to be increasing, and the output during the year will probably greatly exceed that of 1942. Moreover, production is likely to be still greater after the war, when greater quantities of ammonia, from which it is prepared, will be available.

Besides being a source of readily available nitrogen, at a time when it is most desirable that all sources of agricultural nitrogen should be utilized, urea is especially valuable to the farmer because it is less easily leached from the soil than is nitrogen in the form of nitrates.

The present circular discusses the various forms in which urea is obtained commercially, its relation to crop production and to the soil, and its role as a constituent of fertilizers.

NITROGEN FERTILIZERS

The use of nitrogen-containing materials as fertilizers has increased considerably in the United States during the last 30 years. The total quantity of such materials used in 1910 amounted to about 1,820,000 tons. It rose to approximately 2,460,000 tons in 1925 and to about 2,860,000 tons in 1937, the increases over 1910 being 35.2 and 57.1 percent, respectively. The increases in the quantity of nitrogen contained in these materials were very much larger, amounting to 89.3 and 196.9 percent, respectively, since the average nitrogen content of the materials used increased from 7.77 percent in 1910 to 10.88 percent in 1925 and to 14.68 percent in 1937.

Nitrogen-containing materials are conveniently classed, according to the form of their nitrogen content, as natural organic, ammoniacal, nitrate, and synthetic organic. A few materials contain more than one form of nitrogen, and consequently these materials are listed in more than one class. The natural organic materials are numerous, including cottonseed, linseed, and other seed meals, castor pomace, cocoa by-products, garbage and animal tankages, dried blood, fish, shrimp and crab scraps, and bird and bat guanos. The ammoniacal materials comprise ammonium sulfate, ammonium phosphates, ammonia liquor, anhydrous liquid ammonia, ammoniating liquors, and ammonium nitrate. The nitrate materials include sodium nitrate, potassium nitrate, calcium nitrate, and ammonium nitrate, and some of the ammoniating solutions. The synthetic organic materials include calcium cyanamide and urea.

The quantities of the different forms of nitrogen consumed in fertilizers in 1910, 1925, 1937, and 1941 are shown in table 1. Inspection of the table shows that the quantity of nitrogen derived from natural organic sources has decreased, whereas that derived from each of the other sources has increased; also that although the nitrogen from synthetic organic sources was only about 1,000 tons in 1910, it has increased to an extent indicating the possibility of its surpassing that from natural organic materials in the near future. In 1910 the sole synthetic organic nitrogen fertilizer material was calcium cyanamide, sold under the trade name Cyanamid, of which about 3,000 tons, containing about 540 tons of nitrogen, were used. In 1925 the consumption of calcium cyanamide had risen to about 68,000 tons, with a nitrogen content of about 14,600 tons. In addition to the calcium cyanamide, 73 tons of a second synthetic organic nitrogen material, urea, containing approximately 33 tons of nitrogen, was also used. All this calcium cyanamide and urea was imported. In 1937 the consumption of nitrogen in calcium cyanamide had risen to about 25,000 tons and that of urea nitrogen to about 7,000 tons. Although all the calcium cyanamide was, and still is, imported, the urea was mostly produced in this country.

TABLE 1.—*Consumption of fertilizer nitrogen in the United States*

Form of nitrogen	Nitrogen used in—			
	1910	1925	1937	1941
	(Short tons)	*(Short tons)*	*(Short tons)*	*(Short tons)*
Natural organic	78,000	63,000	45,000	53,000
Ammoniacal	28,000	83,000	186,000	184,000
Nitrate	35,000	107,000	158,000	166,000
Synthetic organic	1,000	15,000	32,000	47,000
Total	142,000	268,000	421,000	450,000

UREA

DESCRIPTION

Urea is a white crystalline substance, resembling table salt or granulated sugar in appearance. It was discovered in 1799 as a compound occurring in the urine of mammals, particularly in that of the flesh eaters. Since then urea has been found in very small quantities in blood, muscle, saliva, and other animal secretions, in the leaves of spinach and carrots, and in the seedlings of various plants. That fresh farm manure should contain appreciable proportions of urea is naturally to be expected. The decomposition of this compound is largely, if not entirely, responsible for the odor of ammonia about manure piles.

Urea is classed chemically as an organic compound and is found in nature only as a product of life processes. Historically it is of considerable interest, in that it was the first organic compound to be formed artificially, for prior to Wöhler's synthesis of urea in 1828, vital energy was considered to be necessary for the production of organic compounds.

Pure urea contains 46.65 percent of nitrogen, 20 percent of carbon, 26.64 percent of oxygen, and 6.71 percent of hydrogen. Commercial urea is guaranteed to contain 46 percent of nitrogen.

Urea is a relatively light, bulky material. It has an actual specific gravity of 1.32, as compared with a range of about 1.75 to 2.65 for most fertilizer salts. Its apparent specific gravity is usually about 0.63. It is very soluble in water, 67.1 parts dissolving in 100 of water at 0° C. (32° F.) and 97.8 parts in 100 of water at 19.8° C. (67.6° F.). Like many of the inorganic fertilizer materials, it is somewhat hygroscopic; that is, it tends to absorb moisture from the air. Its hygroscopicity increases with rise of temperature, which is also true for the inorganic nitrogen fertilizer materials. The tendency of urea to absorb atmospheric moisture closely resembles that of sodium nitrate, whereas ammonium sulfate is less hygroscopic at most ordinary temperatures.

Production

Although the 73 tons of urea used as fertilizer in 1925 was all imported, urea is now produced on a large scale in this country. (See first tabulation, p. 7.) It is made from carbon dioxide and ammonia. In synthesizing urea, liquid ammonia and carbon dioxide are brought together in an autoclave under high pressure at approximately 200° C. Under these conditions, the ammonia and carbon dioxide combine to form ammonium carbamate, which in turn decomposes to form urea and water. The yield of urea increases when an excess of ammonia is used, but some ammonium carbamate remains unconverted to urea in the autoclave melt in any case. After passage from the autoclave, the melt is subjected to distillation. By this process, ammonia and carbon dioxide, formed by decomposition of the residual ammonium carbamate, are removed and recovered for reintroduction into the autoclave, and the urea is then crystallized from the aqueous solution and dried. The process is continuous, and most of it is conducted under high pressure. The German procedure for making urea is similar to that just described, but instead of separating the crystals from the solution, distillation is continued until a molten residual mass is obtained, which is then sprayed into a chamber where the droplets are cooled to solid granules.

In the preparation of urea, the carbon dioxide serves the purpose, as does sulfuric acid in the manufacture of ammonium sulfate, of forming with the ammonia a solid nitrogen-containing product that can be handled, stored, transported, and used with far less difficulty than gaseous or liquid ammonia or aqueous ammonia solutions. But since 1,000 pounds of ammonia forms 1,763 pounds of urea as against 3,879 pounds of ammonium sulfate, the urea is a much more concentrated nitrogen product than the ammonium sulfate. In fact, as previously stated, pure urea contains 46.65 percent of nitrogen, while pure ammonium sulfate contains only 21.20 percent. The nitrogen content of urea is higher than that of any other solid used as a fertilizer material.

Nonfertilizer Uses

Urea has a number of uses other than as a fertilizer. It is used in making plastics, as a source of nitrogen in fermentation, in pharmaceutical and medicinal preparations, and in the chemical seasoning of lumber. Solutions of urea have been found useful in promoting the healing of wounds in man and farm animals. Recent studies indicate that urea in limited quantity is a fairly good source of nitrogen in feed for ruminants, but that it should never be used as a feed for poultry, hogs, or horses.

UREA FERTILIZER MATERIALS

Pure Urea

Relatively pure urea was used as a fertilizer to a limited extent from 1924 to 1936. This urea was imported from Germany, and its use was largely restricted to the preparation of commercial mixed fertilizers, though some was sold in small packages under the trade name Floranid, particularly for the fertilization of household plants. It was first shipped to this country in the form of a powder consisting of small individual crystals, but this, as a result of the hygroscopicity of the material, frequently caked to a single hard mass in the bag and thus became difficult to use because of the necessity of breaking the mass into smaller lumps, which in turn had to be crushed and ground. Subsequently, however, it was imported in the form of granules, the preparation of which has been described (p. 4). In this form there was less likelihood of the urea forming a cake; and if caking did occur, the mass was usually not very firm, so that it could be easily broken up again, by light jars or blows, into particles of practically the same size and shape as before caking took place.

Uramon

Domestic production of crystalline urea began in 1935, though the urea-ammonia liquor, UAL–A, had been introduced in 1932. Two years later an American product having the trade name Uramon was placed on the market for fertilizer use. It consisted essentially of urea that had been thoroughly mixed with cocoa-shell meal and rock-phosphate dust so as to coat the individual urea crystals with these water-insoluble materials. This coating of the crystals largely prevented caking. In Uramon as now produced, finely ground dolomitic limestone is used instead of the rock-phosphate dust. Uramon is brown because of the cocoa-shell-meal content; it contains 42 percent of nitrogen and is relatively bulky, since it weighs 46.5 pounds per cubic foot, in contrast with 65 to 70 pounds per cubic foot for many fertilizer salts.

Ureor Fertilizer and Calsi-Ureor Fertilizer

In 1938 two new urea-containing fertilizer materials were placed upon the American market with the trade names Ureor Fertilizer and Calsi-Ureor Fertilizer. These were imported from Germany, but importations ceased soon after the outbreak of war in 1939. Ureor Fertilizer was made by mixing granulated urea with a fine siliceous earth as the insoluble coating material and contained 40 percent of nitrogen. Calsi-Ureor Fertilizer was produced by mixing urea with pulverized dolomitic or magnesium-containing limestone and a lime-containing silicate as the insoluble materials and contained 30 percent of nitrogen.

Urea-Ammonia Liquors

In addition to the solid urea-containing mixtures, which can be handled easily and used directly by the farmer for fertilizer purposes, urea-containing liquid products have been placed upon the fertilizer market for use by fertilizer manufacturers, who add them to mixtures of superphosphate and other materials in the preparation of commercial mixed fertilizers. They are shipped to the fertilizer factories in 10,000-gallon tank cars. These liquors consist essentially of solutions of urea in ammonia and water and cannot be used for direct application to soils. Three grades are on the market, termed "UAL–A," "UAL–B," and "UAL–37," respectively. The nitrogen content of each is shown in table 2.

Table 2.—*Nitrogen contents of 3 grades of urea-ammonia liquors*

Form of nitrogen	Nitrogen in—		
	UAL–A	UAL–B	UAL–37
	Percent	*Percent*	*Percent*
Ammonia	30.4	25.2	20.6
Urea	15.1	20.1	9.1
Insoluble organic			7.5
Total	45.5	45.3	37.2

These and other solutions of sodium nitrate or ammonium nitrate in ammonia and water are now very important sources of nitrogen for the fertilizer industry. They are generally called ammoniating liquors or solutions, and the procedure of adding them to the superphosphate-containing mixture is known as ammoniation. The ammoniation of the superphosphate mixture is a comparatively simple operation and consists merely in adding a measured quantity of the ammoniating liquor to a weighed quantity of the mixture in a rotating drum or fertilizer mixer. The free ammonia of the liquor is rapidly absorbed by the superphosphate, and the ammoniated material is discharged from the mixer soon after the introduction of the liquor.

Liquid ammonia was formerly used extensively for ammoniation, but its use has been largely superseded by that of the above-mentioned liquors, because larger quantities of nitrogen can be introduced into fertilizer mixtures by means of the liquors without reversion of the phosphoric acid of the superphosphate to a citrate-insoluble or so-called nonavailable form. The necessity for the addition of other nitrogenous materials to the mixtures is thus largely and often entirely removed.

In addition to the ease and low cost of the ammoniating process, the use of ammoniating liquors possesses several additional advantages: (1) The liquors are the cheapest sources of nitrogen available to the fertilizer industry; (2) they usually yield fertilizer mixtures that drill and store well; (3) their high nitrogen content facilitates the manufacture of high-analysis fertilizers; (4) their low equivalent acidity makes them useful in formulating nonacid-forming or neutral fertilizers; and (5) the free acidity of the superphosphate is neutralized, the rotting of fertilizer bags being thus greatly reduced.

Calurea

Calurea is a compound of urea and calcium nitrate made by intimately mixing these materials in suitable proportions and evaporating the resulting pasty mass to dryness. It contains 34 percent of nitrogen (one-fifth as nitrate nitrogen and four-fifths as urea nitrogen) and 13 percent of lime. It is no longer available on the fertilizer market, because of the cessation of importations from Germany.

CONSUMPTION OF UREA IN FERTILIZERS

The consumption in the United States of urea for fertilizer mixtures (including that in Uramon and similar mixtures but excluding that in Calurea and the urea-ammonia liquors) has been as follows:

Year:	*Short tons*	Year:	*Short tons*
1925	73	1933	1, 500
1926	189	1934	2, 000
1927	407	1935	3, 000
1928	894	1936	4, 000
1929	2, 000	1937	6, 000
1930	8, 000	1938	16, 000
1931	5, 000	1939	24, 000
1932	1, 000	1940	34, 000

Data on the quantities of urea consumed in urea-ammonia liquors are unavailable.

Figures for the imports of Calurea are as follows:

Year:	*Short tons*	Year:	*Short tons*
1928	500	1935	400
1929	300	1936	572
1930	1, 000	1937	50
1931	2, 139	1938	502
1932	643	1939	116
1933	309	1940	0
1934	599		

COST OF NITROGEN IN FERTILIZER MATERIALS

During the nineteenth century the cheapest sources of nitrogen for use in fertilizers were, in general, the natural organic materials. These, in consequence, supplied most of the nitrogen consumed as plant food; natural sodium nitrate and byproduct ammonium sulfate furnished the remainder. About the beginning of the twentieth century, however, a succession of synthetic nitrogenous products was brought to the fertilizer market at reduced prices for nitrogen, as a result of the development of commercially successful processes for the fixation of atmospheric nitrogen. Though the competition of these synthetic materials has brought about a decline in the prices of the sodium nitrate and ammonium sulfate, the prices of the natural organic materials have actually risen because of their increased consumption as animal feeds, for which they have a greater value than as fertilizer. As shown by table 1, use of the natural organic materials as fertilizers has therefore declined. The use of the cheaper synthetic organic materials, on the other hand, has greatly increased.

The influence of synthetically produced nitrogenous materials in decreasing the cost of nitrogen is shown in table 3, in which are compared the wholesale prices of nitrogen in a number of nitrogenous fertilizer materials since 1900.

TABLE 3.—*Wholesale prices of a unit (20 pounds) of nitrogen in fertilizer materials in stated years*

Year	Sodium nitrate	Ammonium sulfate	Cottonseed meal	Animal tankage	Cyanamid	Urea	Uramon (90 percent urea)
1900	$2.37	$2.79	$2.68	$2.27	----------	----------	----------
1905	2.97	3.01	3.24	2.35	----------	----------	----------
1910	2.76	2.64	3.78	3.36	$3.43	----------	----------
1915	3.04	3.09	3.64	3.22	2.54	----------	----------
1920	4.44	4.08	9.48	8.38	3.40	----------	----------
1925	3.28	2.65	5.69	3.98	2.20	----------	----------
1930	2.49	1.79	5.01	3.78	1.65	$2.23	----------
1931	2.36	1.34	3.14	2.11	1.38	2.09	----------
1932	1.86	1.02	2.07	1.24	1.08	1.75	----------
1933	1.53	1.12	2.71	2.02	1.13	1.94	----------
1934	1.54	1.18	4.37	2.67	1.20	2.34	----------
1935	1.47	1.13	4.51	3.06	1.20	2.30	----------
1936	1.55	1.17	4.13	3.58	1.21	2.02	----------
1937	1.64	1.32	5.15	4.03	1.26	2.02	$1.52
1938	1.68	1.36	3.69	3.14	1.29	2.02	1.37
1939	1.68	1.33	3.85	4.01	1.16	2.02	1.35
1940	1.68	1.37	5.32	3.56	1.20	1.85	1.37

UREA IN RELATION TO CROP PRODUCTION

NITROGEN ESSENTIAL TO PLANT LIFE

Soils that lack available nitrogen cannot produce normal plants. Furthermore, plants on a too-low nitrogen diet yield poorly. It is not difficult to recognize symptoms of nitrogen deficiency, probably first apparent in the foliage, which is a paler green than normal; stunted growth is noticeable; and, if the deficiency is prolonged, the foliage often "rim-fires" and turns purplish on the margins. In serious cases, defoliation ensues.[3]

Nitrogen is a growth-promoting element, and its effect normally is to give the plant a quick start, other conditions being favorable. Plants are thus better able to utilize phosphorus, potassium, calcium, magnesium, and other available nutrient elements, and to reach the productive stage in much better condition than would be possible when there is a deficiency of nitrogen in the soil. It is especially important that sufficient available nitrogen be present in the soil during the early growth of the crop. For this reason an application of available nitrogen is very important early in the growing season, to counteract the leaching action of winter rains and snows.

EVALUATION OF UREA FOR FERTILIZER USE

The Bureau of Plant Industry, Soils, and Agricultural Engineering, in cooperation with different State agricultural experiment stations, has conducted a wide range of field studies to evaluate urea as a source of nitrogen for different crops, in comparison with standard nitrogen sources, as sodium nitrate, ammonium sulfate, and certain of the organic nitrogen sources, including tankage, cottonseed meal, fish scrap, and other organic sources.[4] Urea proved uniformly to be an excellent source of nitrogen for plants.

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[3] For detailed descriptions and illustrations of nitrogen-deficiency symptoms exhibited by different crops, the reader is referred to HAMBIDGE, G., ed. HUNGER SIGNS IN CROPS, A symposium published jointly by the American Society of Agronomy and The National Fertilizer Association. 372 pp., illus. Washington, D. C [1941.]

UREA IN RELATION TO THE SOIL

Changes Urea Undergoes in the Soil

Urea, being readily soluble in water, dissolves rapidly in soil moisture. The dissolved urea is then converted to ammonium bicarbonate by the action of soil bacteria and certain enzymes that are normally present in the soil. Under soil conditions conducive to plant growth, the change to ammonium bicarbonate is generally complete within 3 days. The ammonium bicarbonate, however, is a basic material and reacts with the soil acids as quickly as it is formed. As a result, the acidity of the soil is reduced and the ammoniacal nitrogen becomes in part chemically held in the extremely fine particles of clay and organic matter of the soil. When so condensed with the soil the nitrogen is much less subject to leaching, particularly in soils with a moderate to high clay content, but is still available for use by growing crops.

The ammoniacal nitrogen that is not used by the crops or is lost by leaching may in turn be converted to nitrate nitrogen by the action of soil bacteria. As this conversion progresses, the acidity of the soil again increases. The rate of the conversion will depend on how favorable the conditions are for bacterial action. The major factors involved are moisture content, soil temperature, reaction of the soil, and the supply of available phosphorus and potassium and of neutralizable calcium or magnesium compounds in the soil. Under field conditions the conversion from ammoniacal to nitrate nitrogen is relatively slow for upward of 15 days and does not reach a maximum until about 1 month, on the average, after application of the urea.

Resistance to Leaching

Urea nitrogen is relatively resistant to leaching. Fertilizer mixtures containing urea gave good results in wet seasons when more readily leached sources of nitrogen gave comparatively poor results.[5] In very wet seasons it is not to be expected that any source of nitrogen will give good results, particularly on open, sandy soils. The leaching-resistant property of urea nitrogen may be explained on the basis of the reactions it undergoes in the soil. As long as it remains as urea it is subject to leaching, but conversion to ammonium bicarbonate is very rapid. Once that reaction takes place, there is little danger of leaching until nitrates are produced. The change-over to nitrates is gradual. In practice, the growing crop absorbs the nitrates about as fast as they are formed. The danger of the leaching of nitrogen is greater when nitrates are present in quantity before the crop reaches the stage of growth where it is rapidly utilizing nitrogen. Hence, the importance of rate and time of application of quickly available nitrogen materials.

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[4] Experimental studies on urea in comparison with standard nitrogen sources were conducted by the Bureau of Plant Industry, Soils, and Agricultural Engineering, with reference to various crops, in cooperation with the Maine, New Jersey, New York, Pennsylvania, and North Carolina Agricultural Experiment Stations and the Virginia Truck Experiment Station, on potatoes; with the North Carolina and South Carolina stations, on cotton; with the Georgia, Maryland, North Carolina, and South Carolina stations on tobacco; and with the North Carolina station, on sweetpotatoes and strawberries. The broad scope of this experimental work introduced a wide diversity of soil and climatic factors.

[5] Brown, B. E., Owen, F. V., and Tobey, E. R. SOURCES OF NITROGEN FOR POTATO FERTILIZERS IN AROOSTOOK COUNTY. Maine Agr. Expt. Sta. Bul. 354, 38 pp., illus. 1930. (Cites other references to the influence of wet and dry seasons on nitrogen sources.)

On very sandy soils urea is more leaching-resistant than ammonium sulfate, because the ammonia produced from urea is more completely absorbed by the soil. In the case of ammonium sulfate the sulfate part of the compound tends to keep the ammonia in solution and therefore subject to leaching. This difference between the two materials is probably most important on very sandy soils, such as are used to some extent for citrus and peach culture.

The almost complete absorption of urea nitrogen by the soil not only reduces leaching but minimizes the effect of the fertilizer on the concentration of the soil solution. A given quantity of nitrogen from urea increases the concentration of the soil solution about half as much as would the same quantity of nitrogen from ammonium sulfate and one-fourth as much as would that from sodium nitrate.

Availability of Urea Nitrogen

Like other soluble nitrogen fertilizers, urea is quickly available to crops. Most agricultural crops will assimilate nitrogen in the form of urea, ammoniacal, or nitrate nitrogen. The rapidity of crop response to different forms of nitrogen varies with crop and soil conditions. Some seedlings absorb and respond to urea and ammoniacal nitrogen somewhat more rapidly than to nitrate nitrogen. Lawns, pastures, and small grains apparently respond with about equal rapidity to the three forms of nitrogen. Leafy vegetable crops respond somewhat more rapidly to nitrate fertilizers. This is probably due to the more rapid penetration of nitrate nitrogen into the root zone, especially in dry seasons. The same may be true of cotton and corn, although experiments indicate no substantial difference in the efficiency of the three forms of nitrogen on limed soils.

All the nitrogen in urea fertilizers is available to the crop, but the crop seldom gets all the applied nitrogen. A portion of the urea nitrogen is used by soil microorganisms, and there are some losses by leaching, but the percentage of applied nitrogen recovered in the crop is usually high.

Influence on Soil Reaction

The residual effect of nitrogen fertilizers on soil reaction is one of the important factors influencing their efficiency, especially when used year after year on the same fields. In the humid section of the United States most soils have become acid through cropping, use of acid fertilizers, and leaching of basic compounds. The continual use of acid-forming nitrogen fertilizers reduces the productivity of such soils, unless they are limed at intervals.

Urea nitrogen fertilizers are acid forming, as indicated in table 4. A given quantity of nitrogen in the urea fertilizers—Uramon, Ureor Fertilizer, and urea ammonia liquors—produces the same degree of residual acidity as in cottonseed meal or in dried blood. All these materials are one-third as acidic as ammonium sulfate. Two other urea-containing compounds, Calsi-Ureor Fertilizer and Calurea, produce a lower residual acidity, amounting to an equivalent acidity of 9 and 16 pounds, respectively, of calcium carbonate per unit of nitrogen. Sodium nitrate and cyanamide, on the other hand, are basic. Their continued use tends to reduce the acidity of soils.

TABLE 4.—*Nitrogen content and equivalent acidity of nitrogen fertilizers*

Fertilizer	Nitrogen	Equivalent acidity or basicity (B), $CaCO_3$	
		Per unit of nitrogen	Per 100 pounds of product
	Percent	*Pounds*	*Pounds*
Uramon	42.0	33	70
Ureor Fertilizer	40.0	32	64
Calsi-Ureor Fertilizer	30.0	9	14
Urea ammonia liquors	45.5	36	82
Calurea	34.0	16	28
Ammonium sulfate	20.5	107	110
Sodium nitrate	16.0	36B	29B
Cyanamid	22.0	57B	63B
Cottonseed meal	7.0	29	10
Dried blood	13.3	35	23

Mixed fertilizers frequently contain enough limestone or dolomite to correct the acidity produced by the nitrogen fertilizers used in the mixture. When this is so, the relative influence of the different nitrogen fertilizers with respect to acidity is unimportant. Such mixed fertilizers are usually guaranteed to be neutral or nonacid forming.

RESIDUAL EFFECT ON CROP GROWTH

The rapid availability of urea nitrogen to crop plants suggests little residual effect from this fertilizer material on crop growth after the season of its application to the soil. There is, however, probably an indirect influence to consider, for under some conditions during its first season of application the urea nitrogen may so stimulate plant growth, even weed growth after crops are either harvested or laid by, that the increased plant residues and root growth thus given to the soil will carry their influence through to succeeding crops.

EFFECT ON SOIL BACTERIA

The application of urea influences the bacterial flora of the soil primarily in two ways: (1) The soluble nitrogen furnishes food for the bacteria; and (2) the mild increase in soil acidity reflects itself in the numbers and kinds of bacteria, particularly if the urea is used more or less continuously. When a large quantity of straw or other organic material is turned under, it is good practice to add urea to the soil to furnish a source of available nitrogen for the bacteria that are instrumental in breaking down the straw. Otherwise the bacteria would compete with the crop for any available nitrogen in the soil. Liming, if required, would have to be considered too.

PROPER USE OF SOLUBLE NITROGEN FERTILIZERS

Precautions To Be Observed

Certain points in the use of urea and other nitrogenous fertilizer materials need particular consideration. Too much nitrogen may delay maturity and may force leaf growth at the expense of seed or fruit. Heavy applications to fruit trees late in the season may produce a succulent growth that will not withstand winter conditions. There is also the danger of injuring the carrying qualities of certain fruits and vegetables. When applying urea, ammonium sulfate, sodium nitrate, or other fertilizer salts, care should be taken not to get the fertilizer on the foliage of row crops and thus to avoid burning.

Methods of Applying Urea

Over small areas urea may be applied by hand, but for any large area a fertilizer distributor will prove more satisfactory. Special attachments to planters and cultivators are sometimes used. To insure uniform distribution in top-dressing vegetable crops, it may be advisable to dilute the urea with dry sand, soil, or other inert material.

In applying urea to fruit trees it is convenient to measure the material by volume. Small pails serve well for this purpose, if each pail is marked conspicuously on the inside to indicate the bulk quantity to be used per tree. For example, if 4 pounds of urea is to be applied per tree, the material can be poured into pails marked for that measure. If trees in other sections of the orchard are to receive a different quantity, the pails can be marked accordingly. In making the application, most of the material should be spread broadcast in a broad ring under the outer spread of the branches. As urea is soluble in water, rainfall will wash it into the soil.

EFFECT OF UREA ON QUALITY OF CROPS

In addition to increasing yields, urea, like other soluble nitrogen salts, is used to improve the quality of crops. Crops grown quickly with an ample supply of available nitrogen may be more tender and have a better color. This applies especially to kale, lettuce, spinach, and other leafy vegetables. Too much nitrogen may produce a crop that will not transport well. In orchards, care needs to be exercised in the use of nitrogen, because if too much is used, the quality of fruit is likely to be lowered, owing to lack of good color development. Application of urea to meadows and pastures has been found not only to improve the yield but also to increase the protein content of the crop. A similar increase of protein content has been found in small grains.

USE OF UREA FERTILIZER MATERIALS

Direct Use of Urea Fertilizers

Nitrogenous materials are used extensively in fertilizing crops. In fact, about 45 percent of the fertilizer nitrogen used in the United States is applied unmixed with other fertilizer materials. The direct use of nitrogen fertilizers is practical (1) in regions where the use of phosphoric acid and potash is not profitable; (2) in top-dressing small grain crops, orchards, pastures, hay lands, and lawns that have received previous applications of complete fertilizer; and (3) in side-dressing row crops, as cotton, corn, and vegetables, that received a complete fertilizer at planting.

Urea fertilizers may be used for all these purposes in the same way as the more common nitrogen fertilizers ammonium sulfate and sodium nitrate. The urea fertilizer Uramon contains 42 percent of nitrogen, so the quantity applied would be only half as much as in using ammonium sulfate and about 40 percent as much as in using sodium or calcium nitrate. This means a substantial saving in all handling costs as well as a convenience in the field.

The high nitrogen content of urea fertilizers may make it necessary to distribute rather small quantities per acre. Application at low rates is made easier because the urea fertilizers are rather light and bulky. A 100-pound bag of Uramon contains approximately 4,100 cubic inches of fertilizer as compared with 2,400 cubic inches in a 100-pound bag of sodium nitrate. In other words, Uramon is 70 percent bulkier than sodium nitrate. The volume of Uramon required to make a given application of nitrogen is two-thirds that of nitrate of soda and about three-fourths that of ammonium sulfate. This difference in the volume-weight ratio of materials must be compensated for in the calibration of fertilizer distributors.

Use in Commercial Mixed Fertilizers

Urea-ammonia liquors are used only in the manufacture of commercial mixed fertilizers. The usual practice is to use 65 to 110 pounds of urea-ammonia liquor, equivalent to 30 to 50 pounds of nitrogen, per ton of complete fertilizer, to furnish a portion of the required nitrogen. The liquor is added as all other fertilizer materials are being mixed in a closed rotary fertilizer mixer. The ammonia in the liquor reacts with the superphosphate, has an excellent conditioning action, reduces caking in storage, and materially facilitates fertilizer manufacture.

Uramon is extensively used in the manufacture of complete fertilizers, but the quantity per ton is subject to some limitations. The following general rules should be observed in the use of Uramon in complete fertilizers that are to be held in storage for a considerable period of time: (1) The superphosphate should be neutralized by the addition of ammonia liquor, hydrated lime, or pulverized Cyanamid. (2) In dry-mixed (nonammoniated) mixtures containing Uramon, it is advisable to include 100 to 200 pounds of ammonium sulfate per ton, though not necessary in mixtures containing potassium sulfate or when substantial quantities of natural organics or conditioning agents are used. (3) It is safe to use about 100 pounds of Uramon per ton in most fertilizer mixtures; the quantity that can be used depends somewhat on the other constituents. Combinations of Uramon and nitrate of soda, low-grade potash salts, and wet organics should be avoided as far as possible.

Uramon is being used in some high-analysis fertilizers in quantities as great as 250 to 400 pounds per ton. Such mixtures are usually more hygroscopic than standard grades of fertilizer and are shipped in moisture-proof bags.

USE IN HOME-MIXED FERTILIZER

Uramon can be used in home-mixed fertilizer to good advantage, especially when high-analysis fertilizers of low acidity are desired. Uramon mixtures are relatively free from caking. The following examples are given to illustrate how Uramon may be used in home mixtures:[6]

Mixture 1 (6–12–6):	*Pounds*
Uramon (42 percent N)	286
Superphosphate (20 percent P_2O_5)	1, 200
Muriate of potash (60 percent K_2O)	200
Pulverized dolomitic limestone	314
Total	2, 000

This may be taken as a good general-purpose fertilizer. The formula might be varied by substituting 103 pounds of ammonium sulfate for 50 pounds of Uramon and 53 pounds of dolomitic limestone.

Mixture 2 (6–8–4):	*Pounds*
Uramon (42 percent N)	143
Ammonium sulfate (20.5 percent N)	293
Superphosphate (16 percent P_2O_5)	1, 000
Muriate of potash (60 percent K_2O)	135
Pulverized dolomitic limestone	429
Total	2, 000

This mixture may be used for cotton. Half the nitrogen is from Uramon and half from ammonium sulfate. There is enough dolomitic limestone to make the mixture nonacid forming and to furnish some magnesia (MgO).

Mixture 3 (8–16–20):	*Pounds*
Uramon (42 percent N)	254
Ammonium sulfate (20.5 percent N)	260
Double superphosphate (48 percent P_2O_5)	667
Muriate of potash (60 percent K_2O)	667
Pulverized dolomitic limestone	152
Total	2, 000

This mixture may be used in the New England States, especially for potatoes. Two-thirds of the nitrogen is derived from urea. The fertilizer is acid forming. The dolomitic limestone could be replaced by more concentrated sources of magnesia, if desirable. Ammo-phos could replace the double superphosphate as a source of phosphoric acid, in which case the ammonium sulfate could be lowered to offset the nitrogen in the Ammo-phos.

Mixture 4 (10–6–4):	*Pounds*
Uramon (42 percent N)	285
Sodium nitrate (16 percent N)	250
Ammonium sulfate (20.5 percent N)	200
Superphosphate (20 percent P_2O_5)	600
Muriate of potash (60 percent K_2O)	134
Pulverized dolomitic limestone	531
Total	2, 000

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[6] In these sample mixtures, any need for soluble magnesia or other secondary element should be taken care of.

This mixture is suitable for orchard fertilization. It contains urea, nitrate, and ammoniacal nitrogen, and is slightly basic. The mixture is hygroscopic and should be used soon after it is prepared.

Mixture 5 (7–6–5):	*Pounds*
Uramon (42 percent N)	115
Nitrate of soda (16 percent N)	113
Ammonium sulfate (20.5 percent N)	292
Cottonseeed meal (7 percent N)	200
Superphosphate (16 percent P_2O_5)	750
Potassium chloride (60 percent K_2O)	167
Pulverized dolomitic limestone	363
Total	2,000

This mixture may be used for early potatoes and truck crops on sandy soils in the southern trucking regions. It is high in available nitrogen. On heavier soils, especially where manure or leguminous cover crops have been used, less nitrogen may be needed, and a 6–6–5, a 6–8–6, or a 5–7–5 fertilizer mixture may be more economical.

Mixture 6 (4–12–4):	*Pounds*
Uramon (42 percent N)	100
Ammonium sulfate (20.5 percent N)	186
Superphosphate (20 percent P_2O_5)	1,200
Potassium chloride (60 percent K_2O)	134
Pulverized dolomitic limestone	380
Total	2,000

This mixture, relatively high in phosphoric acid, has been recommended for small grains, pasture, etc. The excess of dolomitic limestone will help to neutralize acid soil.

In home-mixing fertilizers it is usually desirable to use as few materials as possible, as in mixture 1. Even the dolomitic limestone could have been omitted, but it makes the fertilizer nonacid forming, provides magnesia and calcium, and generally is a good conditioning agent.

Only one of the mixtures (mixture 5) contains organic conditioning material. Such materials are not needed under most conditions. For best condition for handling in the field, the materials should be mixed just before they are used.

Use on Individual Crops

Cotton is usually fertilized with a complete fertilizer at planting and side-dressed with an available nitrogen material after chopping, particularly if the fertilizer is low in nitrogen. Urea fertilizer may be applied at the rate of 50 to 75 pounds per acre.

In corn production in the Southeastern and Southern States, nitrogen is frequently the limiting factor. Most experiment stations recommend side dressing with a nitrogen fertilizer when the corn is 12 to 18 inches high. Using 75 to 100 pounds of urea fertilizer will give the recommended quantity of nitrogen and has given good results.

Wheat, oats, and other small grains give profitable response to spring top dressing of nitrogen fertilizers in most of the Southern, Eastern, and East Central States. The best rate of fertilization depends on many factors but will average about 20 pounds of nitrogen per acre. Urea fertilizer may be broadcast at the rate of 40 to 60 pounds per acre.

Pastures and hay lands are frequently top-dressed with a nitrogen fertilizer in addition to being treated with a complete fertilizer. A top dressing of urea fertilizer at the rate of 75 to 100 pounds per acre helps to increase the growth and protein content of pasture or hay.

Most orchards require regular fertilization for profitable production. Best returns have been obtained from nitrogen fertilizers, but the need for phosphorus and potassium is evident in many orchards, particularly in the Atlantic Coastal Plain and in a few areas elsewhere. As a result, the need for these elements is met by the use of high-nitrogen, complete fertilizers instead of nitrogen materials. Such fertilizers as 7–7–7, 10–6–4, and 16–10–8 are being used to a considerable extent. The following quantities of urea fertilizer have been recommended for annual application to apples: 1- and 2-year-old trees, 1 to 2 ounces; 3- and 4-year-old trees, 4 to 6 ounces; 5 years and older, 2 ounces per year of age up to 4 pounds per tree. It should be considered that if orchards are being grown in nonlegume sods the rate should usually be about the maximum indicated, whereas under cultivation the minimum should prove sufficient. These quantities are given as a general guide and must be modified to suit various conditions, as soil type, use of cover crops, and vigor and age of the trees. The foregoing suggestions with reference to the use of urea on different crops are applicable to the use of sodium nitrate, ammonium sulfate, and other quickly available sources of nitrogen, provided an equivalent quantity of nitrogen is furnished.

Urea fertilizer should be applied to orchards late in fall or early in spring. The use of urea or other nitrogen fertilizers should be combined with the necessary application of phosphate and potash fertilizers and lime and with good orchard management.[7] In orchards where cover crops are grown, it is customary to use complete fertilizer on the cover crop, coupling this with a dressing of an available nitrogen material about the trees.

Grapes and small fruits may be fertilized with urea fertilizer at the rate of about 75 to 100 pounds per acre. These crops also respond to complete fertilizers. In most cases the urea fertilizer should supplement the complete fertilizer.

Use for Gardens and Lawns

Urea is especially useful for spring applications to garden crops needing an early start. It has a tendency to delay maturity if applied too late in the growing season. Such crops as lettuce, early cabbage, and spinach are benefited by early applications of urea. This is especially true of vegetables that are eaten raw or as salads and those in which rapid growth, insuring succulence, is desirable.

In making surface applications, urea should not be applied too near the growing plant and should not be allowed to touch the foliage or stems, especially when wet, as serious injury to the tissue may result. After the urea has been applied it should be worked lightly into the surface soil. When the first rainfall comes it will be washed into the soil. Generally it will be advisable to make several light applications instead of one heavy dressing.

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[7] Fertilizer studies with both mixed fertilizers and individual nitrogenous materials are being conducted by a number of the State agricultural experiment stations, and results have been issued in various publications. With some of these stations the Bureau of Plant Industry, Soils, and Agricultural Engineering is conducting cooperative studies on the effect of such treatments on fruit production and quality.

As urea furnishes nitrogen alone, it is desirable to use phosphorus and potassium compounds in conjunction with it for garden or truck crops.

For lawns, 2½ pounds of urea, diluted with 15 pounds of cottonseed meal or similar organic byproduct material, makes a good early-spring treatment, thus providing the grass with a supply of available nitrogen at a time when nitrogen is apt to be lacking. This quantity will be enough for 2,000 square feet of lawn area. The mixture should be applied before a rainfall or should be well watered after being applied.

SPECIAL USES OF UREA FERTILIZERS

For Composts

The maintenance of the organic-matter content of soils is essential in a good fertility program. Farmers usually rely on green manures, animal manures, and crop residues to maintain the organic matter in the soil. For small farms, suburban places, and gardens, the use of composts is widely recommended. These composts may be made from leaves, weeds, straw, grass clippings, and other waste materials. Such materials decompose rather slowly, but the rate of decomposition may be greatly increased by the addition of fertilizer to feed the microorganisms.

A satisfactory fertilizer mixture can be made by using equal quantities of Uramon, superphosphate, muriate of potash, and limestone. The mixture should be used at the rate of about 100 pounds per ton of straw or leaves. If the compost contains a considerable quantity of grass clippings, the quantity of fertilizer may be reduced to 75 or 50 pounds per ton.

The compost pile should be built in 6-inch layers, each layer of which is treated with the fertilizer. Every layer should be watered and the completed pile kept moist in order to hasten bacterial decomposition. A well-made compost pile decomposes rapidly in warm weather and makes excellent material for mulching flower beds, lawns, and gardens.

For Making Humus From Crop Residues

In any soil-fertility program, maximum use should be made of crop residues in order to maintain the organic matter in the soil. Straw, cornstalks, cotton stalks, and similar material properly handled are excellent for this purpose. These materials are too low in nitrogen to be very useful or to decompose satisfactorily. The residues will rapidly be converted to humus, however, if readily available nitrogen, such as urea, is applied when they are plowed under. The principle is the same as in making composts. The compost or manure is made in the soil rather than in a pile. Good results have been obtained when 50 pounds of urea fertilizer have been broadcast for every ton of crop residue.

For Starter Solutions and Liquid Fertilizers

It has been demonstrated that transplanted crops, as tomatoes, sweetpotatoes, and tobacco, start off better if a little fertilizer is added to the transplanting water. The term "starter solution" has been applied to such dilute fertilizer mixtures. A variety of fertilizer materials, including urea, may be used in preparing mixtures for starter solutions.

The practice of applying fertilizers in irrigation water has been followed in Hawaii and California and to a more limited extent in other irrigation areas. Urea fertilizers and other suitable nitrogen sources are used in this way. More recently, fertilizers have been applied in solution to truck crops in New Jersey, New York, and other Eastern States. The high nitrogen content and solubility of urea fertilizers have made them useful in such liquid fertilizers. The general use of liquid fertilizers, however, is not to be recommended until additional experiments are made to determine their efficiency and practicality.

U. S. GOVERNMENT PRINTING OFFICE: 1943

For sale by the Superintendent of Documents, U. S. Government Printing Office
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